The Relationship Between Nonword Repetition, Vocabulary, and Reading in Children with Cochlear Implants

Capstone Project

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By

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Abstract

The aim of the present study was to investigate how children with cochlear implants (CI) perform on a nonword repetition (NWR) task compared to their normally-hearing (NH) peers. One hundred and four second-grade children participated in this study: 49 with NH and 55 with severe-to-profound hearing loss who wore CIs. Along with NWR, children were tested on four other measures: phonological processing and working memory, which were evaluated as skills that potentially underlie NWR skills; and expressive vocabulary knowledge and word reading, which were evaluated as skills that are potentially based on NWR skills. The groups' performance on these four measures was compared to their performance on the NWR task.

Results revealed that the largest group difference was seen in scores for the NWR task, with the NH group performing significantly better than the CI group. Additionally, all dependent language measures were found to have a significant positive correlation with NWR for both groups. Phonological awareness had the highest correlation with NWR for both the NH and CI groups. NWR had the highest correlation with word reading for the NH group. NWR had the highest correlation with expressive vocabulary for the CI group. NWR accounted for a significantly larger amount of variance in expressive vocabulary scores for the CI group when compared to the NH group.

In conclusion, the relationship between NWR skills and the dependent language measures in the present study provides evidence for the role of phonological processing in the perception of spoken language and development of expressive vocabulary and reading skills. The results of the present study may have important implications for planning intervention strategies aimed at facilitating spoken language outcomes for children with CIs. Better understanding of the cognitive mechanisms that underlie spoken language skills may aid in the development of intervention strategies to facilitate successful language outcomes for children with CIs.

Dedication

I dedicate this project to my parents, Bill and Tena Sansom, and thank them for their guidance and support.

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Chapter 1: Introduction

During their preschool years, children must learn the perceptual processing skills that are required to recognize and comprehend spoken language (Nittrouer, Caldwell, Lowenstein, Tarr, & Holloman, 2012). The foundation for these skills is established during infancy. Normally-hearing (NH) infants attend to and learn about the phonologic structure and acoustic features of language naturally, without explicit training to do so. Sensitivity to the phonologic and acoustic structure of language is necessary for the development of auditory processing skills crucial for language development (Henry, Turner, & Behrens, 2005).

The process of early language acquisition for NH infants is in contrast to that of congenitally deaf infants whose hearing loss is present at birth. Congenitally deaf infants do not have sensitivity to spoken language, and therefore cannot develop spoken language in the same way as NH children (Houston & Miyamoto, 2010). Congenitally deaf children experience auditory deprivation during early neural development in utero. Research has shown that exposure to vocal and music sounds in utero (30-40 weeks gestation) is important for the fine tuning of cochlear hair cells and their connection to the spiral ganglion cells (Graven & Browne, 2008). Research has also shown that acoustic stimulation early in infancy is important for the development of the central auditory pathway and early acoustic processing abilities (Tibussek, Meister, Walger, Foerst, & Von Wedel, 2002). Lack of auditory input in infancy leads to impaired auditory discrimination and processing which hinders the development of normal language skills (Corriveau, Goswami, & Thomson, 2010). In order to facilitate spoken language learning, many deaf children receive cochlear implants (CIs), which provide acoustic stimulation to the auditory system.

The primary goal of cochlear implantation is to facilitate the acquisition of spoken language by providing increased access to spoken language (Ganek, McConkey Robbins, & Niparko, 2012). A CI is an electronic device that converts sound energy into an electrical stimulus. The device works by bypassing the damaged hair cells of the cochlea and directly stimulating the auditory nerve. The internal portion of the CI consists of a receiver-stimulator attached to an electrode array. The receiver-stimulator is surgically implanted into the skull and is connected to an electrode array which is placed near the tonotopically organized basilar membrane in the cochlea. The external portion of the CI consists of a microphone, a signal processor, and a transmitter coil. In order to stimulate the user's auditory system, the microphone receives acoustic signals and sends it to the speech processor where the majority of the processing in a CI is done. The processor (1) filters the input signal into narrowband frequency channels, (2) converts the acoustic signal into digital signals, (3) modifies the digital signals into electrical pulses, and (4) transmits the electrical pulses to the internal receiver/stimulator by means of the transmitter coil. Upon receiving the electrical signal from the transmitter, the internal receiver delivers it to the array of electrodes in the cochlea. When the electrical current is routed to the electrodes in the array, auditory nerve fibers are stimulated, allowing the listener to perceive sound (Moore & Teagle, 2002). The rate and manner in which the electrical current is delivered to the electrodes in the cochlea is determined by the CI coding or processing strategy which is selected by the audiologist. Based on the frequency components of the incoming signal and processing strategy being used, particular electrodes in the array are excited. Electrodes near the base of the cochlea are stimulated by high frequency signals, while electrodes near the apex of the cochlea are stimulated by high frequency signals. In this way, CIs take advantage of the tonotopic organization of the basilar membrane to relay the spectral characteristics of the signal (Moore & Teagle, 2002). The spectral resolution of CIs is poor due to the limited number of spectral channels in the device, as well as spread of excitation on the basilar membrane in the cochlea. When the electric current is delivered to the cochlea, it spreads from the stimulated electrode to other locations on the basilar membrane. As a result, the current of the input signal does not stimulate just an isolated site of auditory neurons, but several, creating a blurred representation of the spectral characteristics of the signal (Loizou, 1998). Additionally, frequency mismatch is common with CIs. Frequency mismatch occurs when the electrode that is designated for a particular frequency is not placed relative to the basilar membrane in the location that corresponds to that frequency, thus creating a mismatch in the spectral characteristics of the signal and the spectral characteristics of the signal the listener perceives. Thus, the fine spectral details of speech that are perceptible to those with normal hearing are not reliably discerned by those who use CIs (Loizou & Poroy, 2001). Research has shown when the speech signal is spectrally degraded, the sensory input to the auditory system is also degraded. This degraded sensory input makes it difficult for children with CIs to recover the phonological structure that is necessary for successful language learning (Henry et al., 2005; Loizou & Poroy, 2001). Lack of sensitivity to the highly refined phonological characteristics of speech can lead to deficits in phonological processing (Henry et al., 2005). Thus, although CIs can restore the auditory sensation to profoundly deaf children, these devices do not return hearing to normal and children who use CIs are likely to face challenges in the development of speech and language.

Pediatric cochlear implantation emerged as a surgical option to provide auditory stimulation to deaf infants beginning in 1990. Since then, researchers have investigated factors associated with successful language outcomes for children who receive CIs. One factor that has been examined extensively is the effect of the child's age at implantation. Research has shown that children who are implanted before age two years demonstrate speech and language skills that more closely match those of their normally hearing peers than children who receive their implant at age four years (Geers, 2004). Although deaf children may be delayed in their language abilities at the time of implantation, if these children are identified and implanted at a young age, their average rate of language development following implantation is similar to that of their normally hearing peers (Svirsky, Robbins, Kirk, Pisoni & Miyamoto, 2000). The fact that early identification and implantation allow deaf children to acquire language skills at a rate comparable to their NH peers suggests that early implantation can reduce the language delays typically seen in young children with profound deafness. Reduced language delays are a product of the fact that early implantation allows children to begin building basic language skills that will serve as the foundation for more complex skills such as reading which are acquired at later ages. When basic skills are learned at a younger age, more complex skills can be developed earlier and the child is able to take advantage of the critical period for language learning (Geers, 2004).

Early identification and intervention for deaf children are important for creating the foundation for language skills that will be acquired during the critical period for language. The critical period hypothesis, originally proposed by Lenneberg in 1967, states that primary language acquisition must occur during the critical period, which is hypothesized to begin in infancy and end around the time a child reaches puberty. Once the critical period for language learning has passed, the ability to learn a language with native proficiency is lost (Lenneberg, 1967). Extensive research has been done to investigate further Lenneberg's hypothesis (Knudsen, 2004; Long 1990). Results of these studies support the existence of critical or sensitive periods for language (Knudsen, 2004). The distinction between critical and sensitive periods can be made with respect to the onset and conclusion of the period (Mayberry & Lock, 2003). According to Lenneberg, critical periods begin and end abruptly (Lenneberg, 1967). Sensitive periods begin and end more gradually than critical periods and are considered a period of maximal sensitivity. Following the conclusion of a sensitive period, the phenomenon of interest may occur later on in life, however, it will require greater effort. Recently, researchers have concluded that the term “critical period” may not be entirely appropriate when referring to language acquisition. The term “sensitive period” is more appropriate because the critical period for language actually displays more gradual, rather than abrupt transitions. Deaf children who are fit with hearing aids following identification of their hearing loss and receive their CIs at a young age (around one year) can begin to detect the acoustic-phonetic characteristics of speech that are important for spoken language development and take advantage of neural flexibility during this sensitive period (Mayberry & Lock, 2003).

The emphasis on early identification of children with hearing loss, along with the introduction of commercially available CIs has had a dramatic effect on the speech and language achievements of prelingually deaf children. CIs provide profoundly deaf children access to spoken language and auditory cues that they would not receive through the use of hearing aids. This increased access to sound, coupled with appropriate audiologic rehabilitation allows children with CIs to achieve speech and language skills that exceed those observed in profoundly deaf children who wear hearing aids (Geers, 2004; Lee, Yim, & Sim, 2012). Although CIs provide increased access to spoken language, most deaf children who receive CIs, even those who have benefited from early identification and implantation, demonstrate speech and language skills that lag behind those of their normally-hearing peers (Nittrouer et al., 2012; Geers, Nicholas, & Sedey, 2003; Johnson & Goswami, 2010). In 2004, Geers conducted a battery of speech and language tasks to measure the speech perception, speech production, language, and reading skills of eight to nine year-olds who received a CI between 24 and 35 months. The results of the Geers (2004) study revealed that only 43% of the children in the study achieved combined speech and language skills within the average range, relative to their NH peers. Other researchers have found that young children with CIs perform poorer than their NH peers on language measures including phonological awareness (Nittrouer et al., 2012), working memory (Lee et al., 2012), and expressive vocabulary (Johnson & Goswami, 2010).

Phonological awareness, working memory, and expressive vocabulary have all been shown to be predictors of reading achievement in elementary-age children (Metsala, 1999; Chiappe, Chiappe, & Gottardo, 2004; Swanson, Zeng, & Jerman, 2009). Children with hearing loss who display deficits in these areas are at a greater risk for deficits in emergent literacy skills, which could hinder future academic success (Catts, Gillispie, Leonard, Kail, & Miller, 2002; Nittrouer et al., 2012).

Phonological awareness refers to the ability to recognize the underlying structure of language (James et al., 2005). The structural units can be words, syllables, or phonemes. The ability to retrieve phonemic structure from a speech signal is largely dependent on the ability to perceive the acoustic cues that characterize each phoneme. If a listener lacks sensitivity to those acoustic cues, it is likely that he or she will display a delay or deficit in phonemic awareness (Nittrouer et al., 2012). Phonemic awareness skills are important in acquisition of reading skills because they are needed to accurately identify, decode, and organize phonemes into meaningful words and phrases (Nithart et al., 2011). Research has shown that children with phonological difficulties (for example children with dyslexia) are at a greater risk of developing reading problems, likely due to the fact that these children experience difficulty recoding the visual representation of a word, or its orthography, into the spoken form of that word, or its phonology (Carroll & Snowling, 2004).

Working memory is a short-term memory mechanism that processes and stores information in the service of completing mental operations (Baddeley, 2007). One of most widely accepted models of working memory is the multi-component model (Baddeley & Hitch, 1974). According to the Baddeley and Hitch (1974) model, there are three subsystems responsible for temporary storage and maintenance of information. The first subsystem is the phonological loop which is responsible for the short-term storage of verbal information. The second subsystem is the visuospatial sketchpad which is responsible for the short-term storage of visual and spatial information. The third subsystem is the episodic buffer which is responsible for short term storage of ‘multi-modal’ information and combining language information with visuo-spatial information. The central executive system is a fourth system that controls the flow of information into and from the other three systems. The central executive system is responsible for filtering out unimportant information, allowing for higher order processing of the information through reasoning, decision-making, planning and comprehension (Baddeley, 2007). An individual’s phonological awareness has a significant impact on working memory skills such that poor phonological representation of a signal hinders the working memory mechanism in the storage of that signal (Nittrouer & Lowenstein, 2014). Working memory is important for the development of literacy skills because reading requires the reader to decode the visual configuration and order of letters into strings of phonological units and retain these strings. The reader must hold this configuration of phonemes in their working memory system to form words. In order to understand sentences, the reader must not only decode single words, but also comprehend syntax, word order, and incorporate context clues. All of this must be done simultaneously so that sentences can be understood. Each time a new sentence is read, it must be held in working memory and integrated with other sentences that have already been read (Gathercole & Alloway, 2008).

Expressive vocabulary is defined as the words a child actively uses when talking, writing or communicating. Vocabulary knowledge requires understanding of both the phonological representation of words as well as their meaning. Research has shown that vocabulary size at age two years can significantly predict subsequent language and literacy achievement up to fifth grade (Lee, 2011). Expressive vocabulary knowledge is especially critical for literacy in deaf children with CIs because expressive vocabulary skills can be used to mediate word recognition where phonological knowledge makes overt decoding of unfamiliar words difficult (Nittrouer et al., 2012).

Nonword repetition (NWR) tasks have been used previously to investigate language skills of NH and hearing-impaired children as well as children with language impairment. NWR tasks reflect phonological awareness (Carter, Dillon, & Pisoni, 2002) and working memory skills (Dillon, Burkholder, Cleary, & Pisoni, 2004). Phonological awareness and working memory are thought to be the underlying basis for NWR because successful completion of the task requires perception, short-term storage and production of unfamiliar phonological sequences (Gathercole & Baddeley, 1990; Gathercole, 1995). Research has also demonstrated a positive correlation between performance on NWR tasks and measures of expressive vocabulary (Casserly & Pisoni, 2013), and reading (Dillon & Pisoni, 2006), with children who demonstrate poor performance on NWR tasks tending to perform poorer on expressive vocabulary and reading tasks. The relationship between NWR, expressive vocabulary, and reading is likely due to the fact that all three measures depend to some degree on phonological awareness and working memory skills (Dillon, Cleary, Pisoni, & Carter, 2004). Successful completion of a NWR task requires (1) accurate recovery of phonemic structure from the acoustic signal, (2) storage of that signal in auditory working memory, and (3) planning and coordination of articulatory movements to correctly produce a response (Sahlen, Wagner, & Nettelbladt, 1999; Dillon et al., 2004). Figure 1 shows a schematic of the relationship between phonological awareness, working memory, NWR, reading, and vocabulary skills. In the figure, phonological awareness and working memory skills serve as underlying constructs of NWR while at the same time, measures of NWR are highly predictive of vocabulary and reading skills.

Research has shown that there is a wide range of NWR skills among children with CIs, with some children displaying high accuracy on the task while others carry out the task with much less precision (Dillon et al., 2004). Of interest in the present study was determining how the 8-9 year old children who use CIs in this study performed on a NWR task when compared to their NH peers. Also of interest was determining how phonological awareness and working memory contribute to NWR for

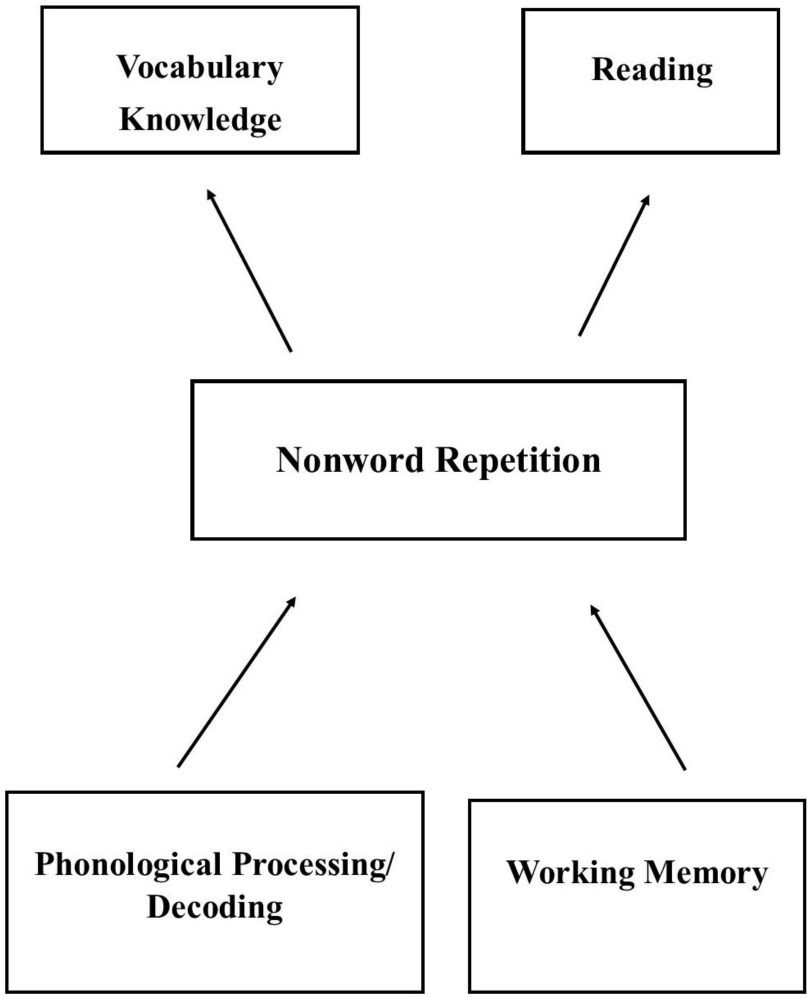

Figure 1- Schematic portraying the proposed relationship between phonological awareness, working memory, vocabulary knowledge, and reading skills relative to NWR skills.

children who use CIs and must perform the NWR task with a spectrally degraded signal. The model tested in the present study was that phonological awareness and working memory facilitate the acquisition of NWR skills. A final question addressed was how performance on a NWR task can serve as an index for the expressive vocabulary and word reading skills of children with CIs. The model tested in the present study was that NWR examines children's sensitivity to phonological structure, including knowledge of phonotactic properties for words in their native language. Therefore, NWR skills contribute to vocabulary acquisition and word reading skills.

I. Purpose

The purpose of the present study was to assess the NWR skills of children with hearing loss who have CIs when compared to their NH peers using a between-groups comparisons. The two primary questions of interest were: Do differences in performance on the task exist between the two groups? And, if a difference does exist, what is the magnitude of difference?

A secondary purpose of this study was to determine the relationship of working memory and phonological awareness to the NWR skills of hearing-impaired children. Specifically, the goal was to determine how working memory and phonological awareness, which are underlying constructs of NWR tasks, explain the variance in NWR scores.

A third purpose of this study was to investigate the proportion of variance in measures of reading and vocabulary that is explained by performance on a NWR task for children with NH and those with CIs. In other words, how well does performance on NWR task relate to reading and vocabulary skills for NH children and children with CIs?

Chapter 2: Methods

I. Participants

Two groups of children participated in the present study during the summers of 2011, 2012, and 2013. All participants were between the ages of 7 years, 10 months and 9 years, 5 months at the time of testing and had just completed second grade. The first group consisted of 49 children (22 males and 27 females) with normal hearing sensitivity. Hearing sensitivity was defined as normal if all pure-tone thresholds from .25 to 8 kHz were better than 15 dB HL. Audiometric measurements made at the time of testing confirmed hearing sensitivity within the normal range. The second group consisted of 55 children (27 males and 28 females) with severe-to-profound hearing loss who wore CI(s). Audiometric measurements made at the time of testing confirmed that there was no residual hearing for any child with a CI. All children with CIs had their hearing loss identified and treatment initiated by 2 years of age: Mean age of identification was 7 months (7 months). The mean better-ear, pure-tone average threshold at 0.5, 1.0, and 2.0 kHz before receiving a cochlear implant was 100 dB HL. Most of these children (80%) received their first CI before turning 2 years of age. Thirty-six children in the second group had bilateral CIs. Of the 19 children in the second group with one CI at the time of testing, six wore a hearing aid on the non-implanted ear.

II. Equipment

All testing took place in one of three sound-attenuated rooms. Stimuli used for testing were presented at 68 dB SPL via computers equipped with Creative Labs Soundblaster digital-to-analog cards using a 44.1-kHz sampling rate and 16-bit digitization. Roland MA-12C powered speakers were used for audio presentation of stimuli. For the phonological awareness task, one speaker was positioned one meter in front of the child. The phonological awareness task used an audio-visual format that included a 1500-kbps data rate and 24-bit digitization in video presentation. With the exception of the phonological awareness task, the participants' responses to all tasks were video and audio recorded using a SONY HDR-XR550V video recorder. Video recording the participants' responses allowed scoring for each task to be completed at a later time. Children wore SONY FM transmitters in specially designed vests that transmitted their verbal responses to the receivers, which provided direct line input to the hard drives of the cameras. This procedure ensured good sound quality for all recordings. Scoring for the phonological awareness task was done at the time of testing by the experimenter entering responses into the computer. All children with hearing loss were tested wearing their customary auditory prostheses, which were checked at the start of testing to ensure proper function.

III.   General Procedures

All testing took place in Columbus, Ohio at The Ohio State University. Data were collected during a series of camps that occurred during the summer after the children completed second grade. Each camp took place over a two-day period and included between four and six children. All children were tested in six individual sessions, each lasting no longer than one hour. Measures collected during three of those sessions are described below, and include children's abilities to repeat nonwords, as well as skills that could potentially explain those abilities.

IV.   Stimuli and Task Specific Procedures

Nonword Repetition. The NWR task consisted of nonword stimuli originally used by Dollaghan and Campbell (1998). The stimuli were sixteen nonwords, four at each of four syllable lengths (one, two, three, four) (ex: nɑɪb, teɪvɑk, ʧinoɪtaʊb, veitaʧaɪdoɪp). The nonwords were constructed so that each began and ended with a consonant, and contained no consonant clusters. No individual syllables in any of the nonwords correspond with an English word (Dollaghan & Campbell, 1998). The nonwords were recorded by a female talker and presented along with a video recording of the words to provide visual cues. Stimuli were recorded by the last author, who is a trained phonetician, which ensured that the stimuli would be recorded as described. Equal stress was placed on all syllables, for all stimuli. The participants were instructed to repeat the nonwords exactly as they were produced in the recorded stimuli. The participants' responses were video recorded. The responses to the NWR task were scored on a phoneme by phoneme basis as either correct or incorrect. Phoneme substitutions, omissions, and distortions were scored as incorrect. Phoneme additions were not scored as incorrect.

Phonological awareness. Phonological awareness was measured using a phoneme deletion (PD) task. The PD task could be considered a test of phonological processing, rather than of just awareness. This is because, to successfully complete the task, children must recognize phonemic structure in a nonword, manipulate that nonword structure so that one segment was removed, and then blend the remaining segments. The segment to be removed could occur anywhere within the word (ex. Say plig without the 'l' sound). The task consisted of 32 items and has been previously used to examine phonological awareness skills in children (Nittrouer, Caldwell-Tarr, Lowenstein, Rice, & Moberly, 2013). The goal of the PD task was not to measure recognition, but rather to evaluate children's sensitivity to phonological structure in the speech signal. Practice was provided before the task. All answers were entered directly into the computer by the examiner and percent correct scores were used as a dependent variable. Two children in the CI group did not complete the PD task due to illness.

Working Memory. Verbal working memory was measured using a task previously employed with children (Nittrouer & Miller, 1999). Ten word lists containing the same six words were presented to the participant through a speaker. The six words were ball, coat, dog, ham, pack, and rake. The order of words was randomized across each list by a computer program. After all the words were presented, pictures of each item in random order, but not matching that of the audio presentation order, appeared at the top of a computer touch screen. The task required the child to touch each picture in the order in which they were presented. When a picture was touched, that picture moved down and into place to the right of the previously selected picture. After all the pictures were touched, they moved into place at the bottom of the computer screen, in order from left to right according to how the participant recalled hearing them. The computer program recorded the responses and compared them to the order in which words were actually presented. Training was completed prior to testing using the letters F, H, Q, R, S, and Y. The training words were produced by the same speaker who produced the word samples. The responses to the working memory task were automatically analyzed the computer software following completion of the testing session. The words recalled in each position for each list were compared to the word orders actually presented. A word was considered incorrect if it was recalled in the wrong list position. The total number of errors across list positions (out of 60) was computed. Total error scores were then converted into percent correct scores by multiplying the proportion of correct responses by 100. This value was used as a measure of accuracy. The software also recorded the response time required for each of the 10 presented lists, and computed the mean time across the all of the lists for each participant.

Expressive Vocabulary. Expressive vocabulary (EV) was assessed using the Expressive One-Word Picture Vocabulary Test (EOWPVT) (Brownell, 2000). This task required the participant to verbally label items shown on separate pages of a test book. Pictures were shown one at a time in a developmental sequence until the participant made seven consecutive naming errors, upon which testing was discontinued. The total number of correctly labeled items served as the raw score for each participant. The raw score was then converted to a standard score based on the participant's age using normative data from the test publishers.

Word Reading. Word reading was assessed using the word reading subtest on the Blue Form of the Wide Range Achievement Test-4 (WRAT) (Wilkinson & Robertson, 2006). In this task, participants first named selected letters of the alphabet. Then, they were asked to read single words from a list of fifty-five, until eleven consecutive reading errors were made. Once the participant made eleven consecutive errors, testing was discontinued. Raw scores for the WRAT were determined by calculating the total number of words on the list that the participant read incorrectly. The raw score was then converted to a standard score based on the participant's age using normative data from the test publishers.

Chapter 3: Results

Scores on all dependent measures were screened to ensure that they were normally distributed and that there was homogeneity of variances between groups. All measures were found to meet criteria to be appropriate for use in inferential and regression analyses; therefore, no transformations were performed. Means and standard deviations were calculated for both the NH and CI groups on all dependent measures. Cohen's ds were calculated to assess the difference in NH and CI group means on each dependent measure, normalized by standard deviation (SD). Independent samples *t* tests were performed to compare the mean scores for each dependent measure between the NH and CI groups. For all measures, $p<.05$ was selected as the significant value.

Group differences

Nonword Repetition. The top row of Table 1 shows mean scores and SDs for the NH and CI groups on the NWR task. For NWR, the total percent phonemes correct (PPC) scores across all 16 stimuli were calculated as Dollaghan and Campbell (1998) had done. An independent-samples t-test on mean scores showed a significant difference between the groups, $t(102) = 7.9$, $p<.05$. Results revealed that children in the NH group performed significantly better than the CI group on the NWR task. The Cohen's *d* revealed that children with CIs scored more than one and a half SDs below the mean total PPC score of children with NH.

Table 1- Mean scores and SDs for dependent measures, along with Cohen's *d*s.

	NH		CI		Cohen's *d*
	M	(SD)	M	(SD)	
NWR Total Percent Phonemes Correct	83.0	(7.1)	67.5	(12.3)	1.6
PD Percent Total Words Correct	71.5	(21.5)	47.6	(32.6)	0.9
Working Memory Percent Correct	56.1	(16.5)	43.3	(15.4)	0.8
EOWPVT standard score	110.0	(13.7)	94.4	(18.1)	1.0
WRAT standard score	110.0	(11.7)	101.0	(14.6)	0.7

Phonological Awareness. The second row of Table 1 shows mean scores and SDs for percent words correct on the phoneme deletion task for both the NH and CI groups. An independent-samples t-test on mean scores showed a significant difference between the groups, $t(100) = 4.9$, $p < .05$. Results revealed that children in the NH group performed significantly better than children in the CI group on the phoneme deletion task. Cohen's *d* revealed that children with CIs scored close to one SD below the mean score of children with NH.

Working Memory. The third row of table 1 shows mean scores and SDs for percent correct on the working memory task for both the NH and CI groups. An independent-samples t-test on mean scores showed a significant difference between the groups, $t(102) = 4.9$, $p < .05$. Results revealed that children in the NH group performed significantly better than children in the CI group on the working memory task. Cohen's *d* revealed that children with CIs scored close to 1 SD below the mean score of children with NH.

Expressive Vocabulary. The fourth row of Table 1 shows mean standard scores and SDs for the EOWPVT for both the NH and CI groups. An independent-samples t-test on mean scores showed a significant difference between the groups, $t(102) = 7.7$, $p < .05$. Results revealed that children in the NH group performed significantly better than children in the CI group on the expressive vocabulary task. Cohen's *d* revealed that children with CIs scored one SD below the mean standard score of children with NH on the EOWPVT.

Word Reading. The fifth row of Table 1 shows mean standard scores and SDs for the WRAT for both the NH and CI groups. An independent-samples t-test on mean scores showed a significant difference between the groups, $t(102) = 2.7$, $p<.05$. Results revealed that the NH group performed significantly better than the CI group on the word reading task. Cohen's *d* revealed that children with CIs scored one SD below the mean standard score of children with NH on the WRAT.

In summary, the largest effect of group difference was seen in scores for NWR, with the NH group performing significantly better than the CI group on the task.

Correlation Results. Analyses were done to examine how well working memory and phonological awareness, which are hypothesized to be major contributors to nonword repetition, explain the variance in NWR scores. Pearson product-moment correlation coefficients were calculated between total PPC and PD, and total PPC and working memory for both groups. These values are displayed in Table 2. For the NH group, both the PD and working memory tasks were found to have a significant positive relationship with total PPC, such that a higher score on the total PPC task correlated with a higher score on the PD and working memory tasks. The PD and working memory tasks were found to have a significant positive correlation with total PPC for the CI group as well, such that a higher score on the total PPC task correlated to a higher score on the PD and

Table 2- Pearson product-moment correlation coefficients among nonword repetition and phoneme deletion and working memory for NH and CI groups

		NH		CI	
		Phoneme Deletion	Working Memory	Phoneme Deletion	Working Memory
Total PPC	Pearson Correlation	.52	.32	.50	.35
	Sig. (2-tailed)	.00	.03	.00	.01
	N	49	49	53	55

working memory tasks. Results suggested that, for both groups, children's abilities to complete the NWR task depends to some extent on their abilities to correctly perceive and store phonological segments.

Next, correlational analyses were done to investigate the proportion of variance in measures of vocabulary and word reading that is explained by NWR for children with NH and those with CIs. Pearson product-moment correlation coefficients were calculated between total PPC and the measures of EV and word reading for both groups. These values are displayed in Table 3. For the NH group, both the EV and word reading tasks were found to have a significant positive relationship with total PPC, such that a higher total PPC score correlated with a higher score on the EV and word reading tasks. The EV and word reading tasks were also found to have a significant positive relationship with total PPC for the CI group such that a higher total PPC score correlated with a higher score on the EV and word reading tasks. Results suggest that, for both groups, expressive vocabulary and word reading depend to some extent on children's abilities to complete a NWR task. Results also show that total PPC accounted for a significantly larger amount of variance in expressive vocabulary scores for the CI group when compared to the NH group, as calculated using a Fisher's r to z transform, z=1.81, p (one-tailed) = .035; p (two-tailed)= .07.

Table 3-Pearson product-moment correlation coefficients among nonword repetition and expressive vocabulary and word reading for NH and CI groups

		NH		CI	
		Expressive Vocabulary	Word Reading	Expressive Vocabulary	Word Reading
Total PPC	Pearson Correlation	.29	.46	.58	.49
	Sig. (2-tailed)	.04	.00	.00	.00
	N	49	49	55	55

In summary, all measures were found to have a significant positive correlation with total PPC for both groups. Phonological awareness had the highest correlation with total PPC for both the NH and CI groups. Total PPC had the highest correlation with word reading for the NH group. Total PPC had the highest correlation with expressive vocabulary for the CI group. Total PPC accounted for a significantly larger amount of variance in expressive vocabulary scores for the CI group when compared to the NH group.

Chapter 4: Discussion

The current study aimed to measure the ability of children with CIs to repeat nonwords compared to their NH peers. Also of interest was how performance on a NWR task could be explained by phonological awareness and working memory skills. Finally, this study aimed to investigate how well performance on a NWR task could explain performance on other language measures, specifically measures of expressive vocabulary and word reading, for children with CIs.

Results revealed that the second grade children with CIs tested in this study performed significantly poorer on the NWR task when compared to their age-matched peers with NH. Poorer performance by children with CIs on the NWR task is not unexpected given that CIs provide a spectrally degraded signal to the listener. As a result of the degraded representation of the signal in the auditory system, recovery of the phonological structure from the signal becomes more difficult (Loizou, 1998; Lee et al., 2012). Similar findings have been reported by Carter et al. (2002) who investigated the ability of children with CIs to complete a NWR task. The researchers found that children with CIs produced only 5% of their nonword imitations correctly without any errors (Carter et al., 2002). Successful completion of a NWR task requires that the listener construct and store a new phonologic representation of the signal based on a single exposure to the stimulus. Therefore, the listener cannot rely on previously formed lexical representations of the stimuli to complete the task (Dillon & Pisoni, 2006). The inability of the CI user to recover an accurate representation of the phonologic characteristics of the signal means that the phonologic representation of the signal that they form, subsequently store in working memory, and ultimately produce vocally will be degraded. Given this information, it is not surprising that the CI group performed less accurately than the NH group on the NWR task.

Results also revealed that performance on the phonological awareness and working memory tasks used in this study was found to have a significant relationship with performance on the NWR task. Correlational analyses revealed that a large amount of variance in NWR scores was explained by scores on the phonological awareness and working memory tasks. This relationship was consistent across both the NH and CI groups. These findings are in agreement with the widely held belief that a major constraint on NWR skills is the quality of temporary storage of the phonological representations of the signal (Gathercole, 2006). In order to successfully complete the NWR task, listeners must perceive the stimulus words and use their knowledge of the phonotactic properties of language to reproduce the novel stimulus they heard as accurately as possible. If the listener is unable to correctly perceive the acoustic signal and interpret it as a phonological pattern, he or she will be unable to correctly complete the NWR task (Gathercole, 2006). Successful completion of a NWR task is also governed by the listener's ability to maintain their perception of the stimulus item in working memory as it is translated into an articulatory pattern and produced vocally (Dillon et al., 2004). While working memory was found to have a significant relationship to NWR, it is important to consider the impact of phonological awareness skills on working memory when interpreting this result. Research has been conducted to investigate the role of phonological structure in temporary storage (Nittrouer & Miller, 1999; Nittrouer, Caldwell, & Lowenstein, 2013). One study completed by Nittrouer et al. (2013) utilized a serial recall task to measure the response time of children who wear CIs. Serial recall tasks have been widely used to measure verbal short-term memory and are generally considered to be an index of processing effort (Gathercole, Frankish, Pickering, & Peaker, 1999; Nittrouer et al., 2013). The results of the Nittrouer et al. (2013) study showed that poor performance on serial recall tasks was a result of problems recovering and coding phonological structure for the items to be stored in working memory, rather than with the processing of the items in the working memory buffer. In other words, any working memory deficits displayed by children with CIs may be explained by these children's deficits in encoding clear phonological representations of the signal (Nittrouer et al. 2013). Considering these findings, poorer performance on the NWR task by children in the CI group when compared to children in the NH group is likely due to their deficit in phonological awareness skills. This finding is supported by previous research that has shown that sensitivity to phonological structure, not temporary storage capacity, underlies NWR skills in typically developing children (Bowey, 1996).

Correlational results also revealed that, for children in the NH group as well as children in the CI group, a large amount of variance in expressive vocabulary and word reading scores was explained by performance on the NWR task. This result is consistent with previous research completed by Casserly and Pisoni (2013) who investigated the NWR abilities of children with CIs. The results of the Casserly and Pisoni (2013) study revealed that performance on the NWR task was positively correlated with vocabulary and reading skills. The relationship between NWR, expressive vocabulary, and word reading is rooted in the idea that all three phenomena are constrained by the quality of the phonological awareness of the listener. NWR tasks serve as an index of phonological processing skills, such that poor phonological awareness skills will negatively impact NWR. NWR abilities are also closely linked to the ability to learn the phonological forms of new words. Children with poor NWR skills also display poor phonological processing skills and are slower to learn the phonological forms of new words. Phonological processing abilities are necessary in the learning of new vocabulary words and learning to read (Gathercole, 2006; Casserly & Pisoni, 2013).

Regarding expressive vocabulary specifically, as a child gains more and more exposure to spoken language, their knowledge of the phonemic structure of language also grows. This increased knowledge of the phonemic structure of language allows children's phonological representations to become more detailed and as a result, they are able to make more generalizations about the phonological structure of language and the likelihood of particular groupings of phonemes (Casserly & Pisoni, 2013). The ability to make generalizations about the phonemic structure of language is important for vocabulary learning. The better a child's phonologic awareness skills, the more successful they will be at decoding unfamiliar words which will eventually become a part of their lexicon (Gathercole, 2006). Successful completion of a NWR task also requires knowledge of the phonemic structure of language. The listener must perceive the stimulus word and interpret it as a phonological pattern before they can reproduce it as a vocal response (Dillon & Pisoni, 2006).

Interestingly, in the present study, NWR accounted for a larger amount of variance in expressive vocabulary scores for the CI group when compared to the NH group. Results of the present study suggest that the stronger relationship between NWR and expressive vocabulary skills for the children in the CI group compared to the NH group reflects a greater reliance by children in the CI group on their phonological awareness skills when completing the expressive vocabulary task compared to their NH peers. Seemingly, NH children rely on language structure other than just phonological structure when developing expressive vocabulary skills. Children with NH have the ability to access structure in language that facilitates new vocabulary learning and the addition of new vocabulary words to their lexicon. Although the exact process by which children use their spoken language skills to extract language structure from the acoustic signal is not known, the results of the present study suggest that children in the CI group may not have the ability to extract this structure with as much success compared to normally-hearing children. The fact that the expressive vocabulary skills of children with CIs seem to rely more heavily on phonological awareness skills is particularly detrimental given that CIs provide only a structural degraded representation of the signal.

Regarding the relationship between NWR and reading skills that was found in the present study, similar results have been reported by Dillon and Pisoni (2006) who conducted a study to investigate the relationship between NWR and reading skills in children who have CIs. The results of the Dillon and Pisoni (2006) study revealed a positive correlation between children’s reading skills and their performance on a NWR task. Learning to read requires the reader to recognize that the spoken form of language, which is expressed by a continuous acoustic signal, can also be represented by sequences of visual symbols in the written form of language (Dillon, de Jong, & Pisoni, 2012). Successful reading also depends on the ability of the reader to recognize spoken words not only as meaningful lexical items, but as a combination of units of sound with internal phonological structure. Poor readers often experience a disconnect between the continuous nature of the acoustic speech signal and the discrete abstract nature of the alphabetic symbols that are used to represent speech in written language (Nittrouer et al., 2012). Phonemic awareness skills are crucial to the understanding of the connection between spoken and written language and the subsequent development of reading skills (Dillon & Pisoni, 2006). The phonological awareness skills that are important for understanding the connection between the spoken and orthographic forms of language are also important for the successful completion of a NWR task. Given that both reading skills and NWR skills rely on phonological awareness skills, it is not expected that these skills were found to be positively correlated in the present study.

Chapter 5: Conclusions

The current study examined the NWR skills of children with CIs, and compared their performance to that of children with normal hearing (NH). The goals of this study were to assess how phonological awareness and working memory skills contribute to performance on a NWR task and to determine how performance on a NWR task could explain performance on tasks of expressive vocabulary and word reading. The results of the present study revealed strong relationships among phonological awareness, working memory, and NWR for both NH children and children with CIs. The results also revealed that NWR skills explain a significant amount of variance in expressive vocabulary and word reading skills for both the NH and CI groups.

In summary, the results of the present study present evidence to support to the relationship between NWR skills and other language skills for children who use CIs. NWR tasks examine children's sensitivity to phonological structure, including knowledge of phonotactic properties for words in their native language. The relationship observed between NWR skills and the language measures used in the present study provide strong evidence for the role of phonological encoding and manipulation in the perception of spoken language and development of expressive vocabulary and reading skills (Casserly & Pisoni, 2013). Difficulties performing a NWR task are an indication of problems with obtaining a phonological representation from an acoustic signal, and are characteristic of individuals with poor language learning abilities (Gathercole, 2006). The relationship between NWR skills and the processing of spoken language has important implications for children with CIs. The primary goal of cochlear implantation is to facilitate the acquisition of spoken language (Ganek et al., 2012). Better understanding of the mechanisms that facilitate spoken language skills, such as phonological processing and working memory, as well as the cognitive mechanisms that underlie the acquisition of vocabulary and reading skills can help develop intervention strategies aimed at facilitating successful language outcomes for children with CIs.

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